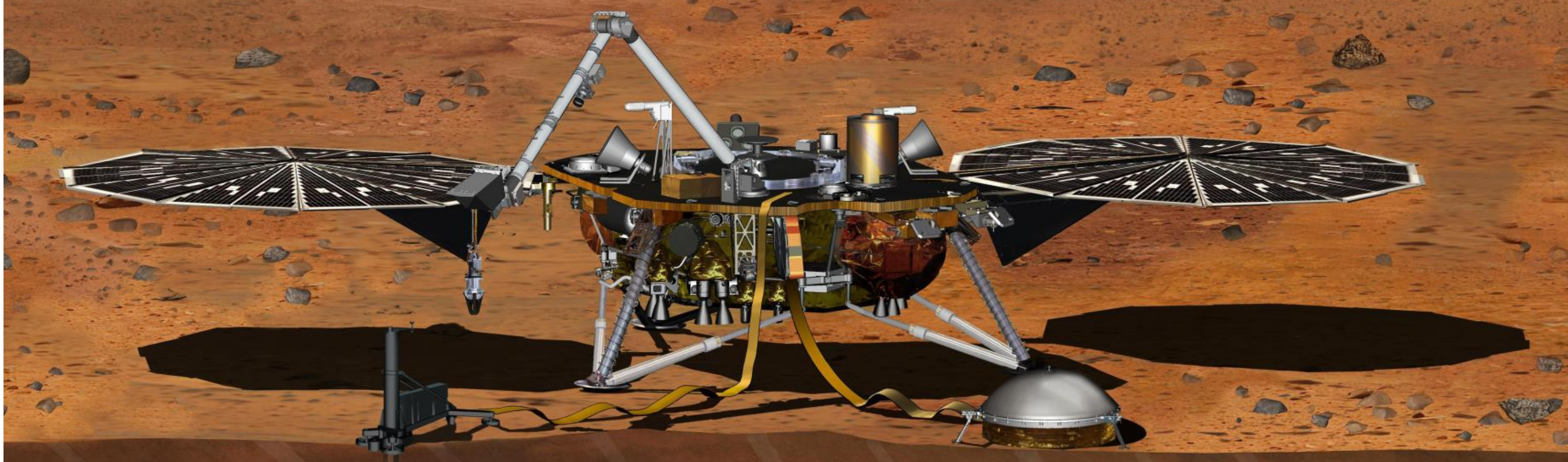
Mars Internal Structure: Seismic Predictions for Core Phase Arrivals in Anticipation of the InSight Mission



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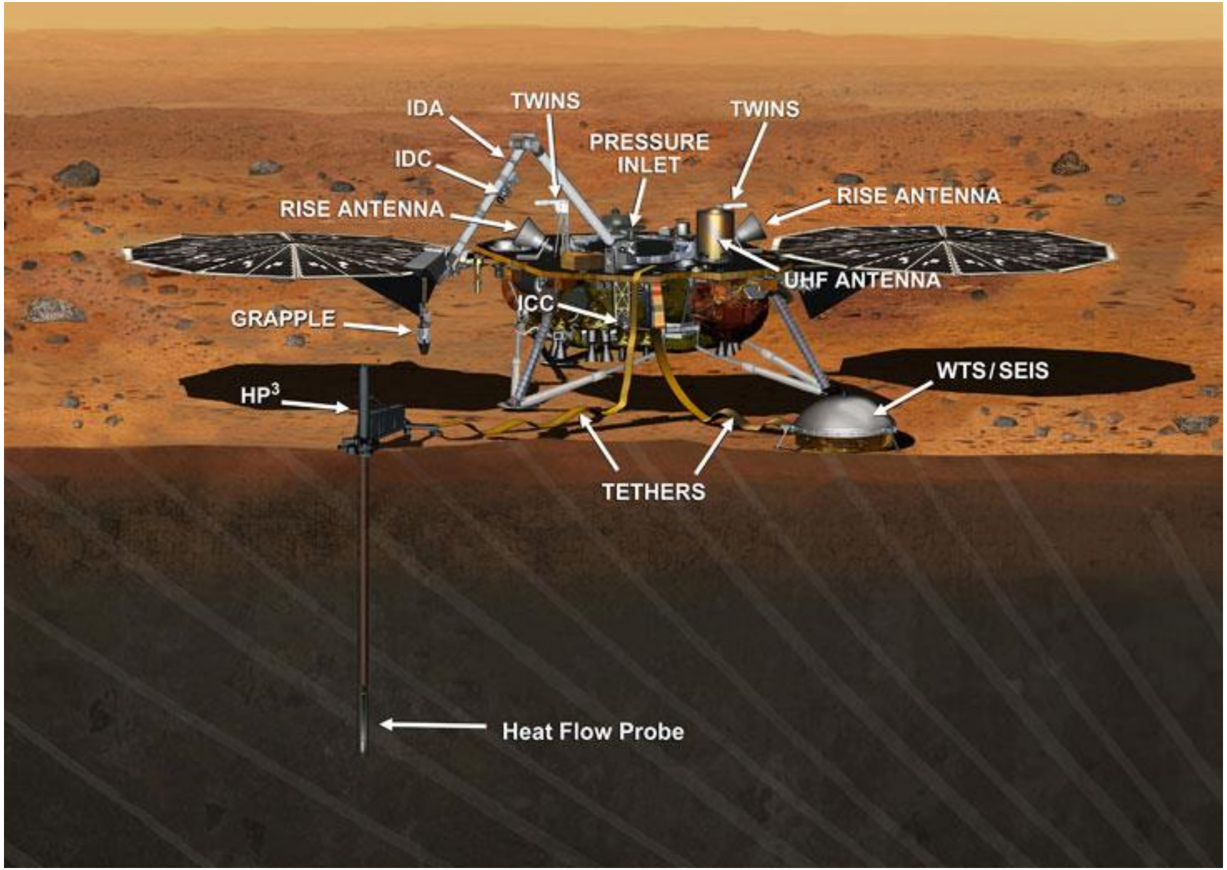
Mission Overview



Launch:
May 2018

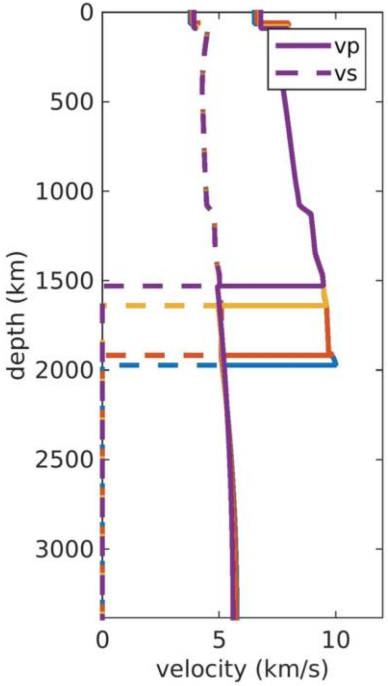
Landing:
November 2018

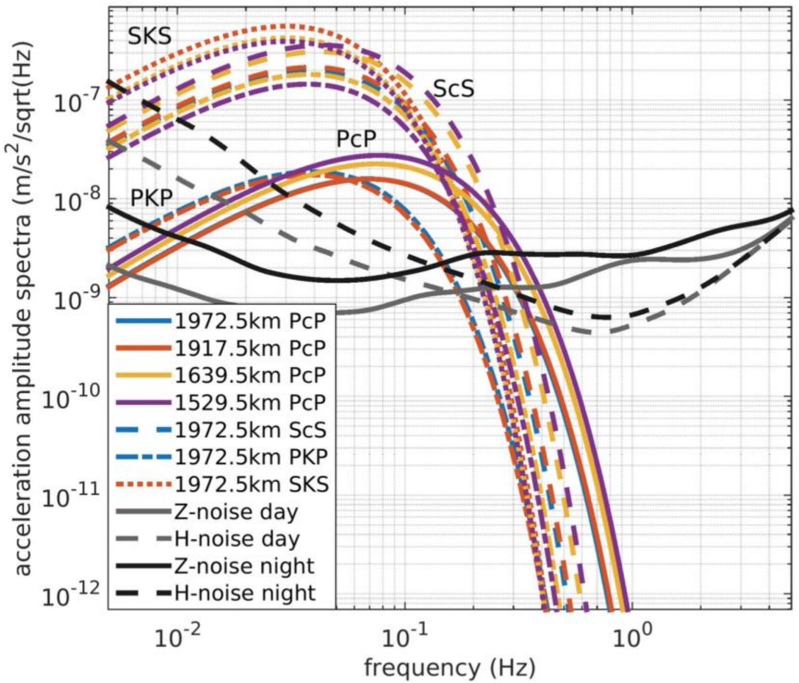
Instrument deployment:
60 sols (including 20 sols margin)

Surface ops:
Just over 1 Mars year (720 days/700 sols)

Marsquake amplitude prediction

Expected amplitudes for marsquakes assuming a medium seismicity model support the likely observation of P and S core phases for events with magnitude greater than M_W 4.6



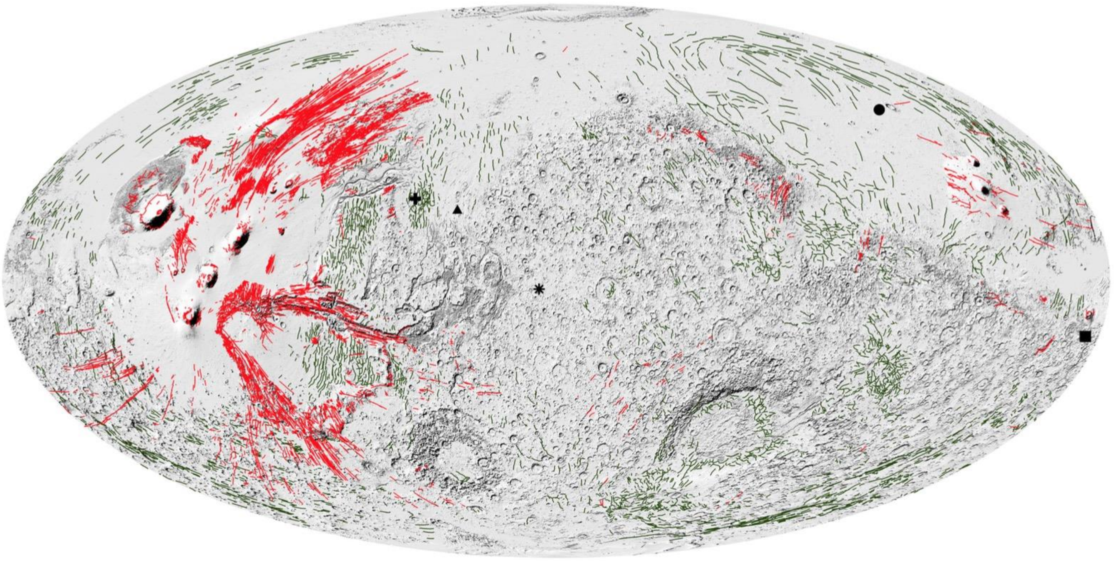


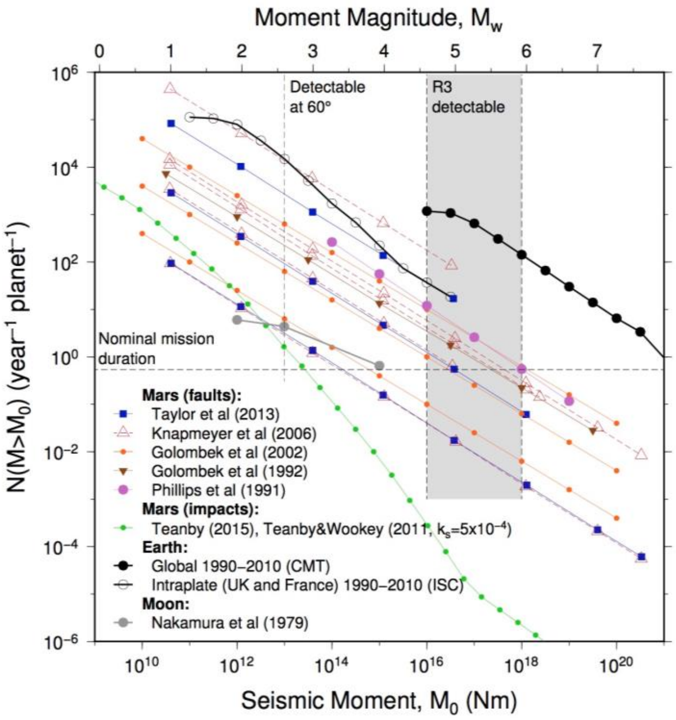
models by Attilio Rivoldini considering different core sizes

new modifications to TauP toolkit* permit calculation of acceleration amplitudes considering intrinsic attenuation, geometrical spreading, reflection & transmission coefficients, free surface correction

*In preparation by Hempel et al. for Seismological Research Letters

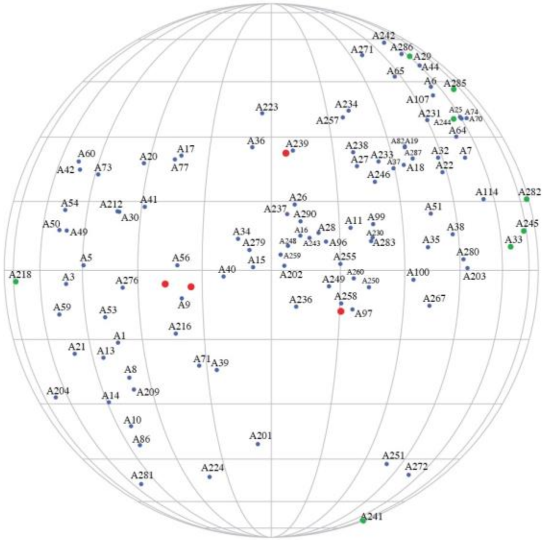
For the mission duration, we would expect to record on the order of 10 events of at least this magnitude.



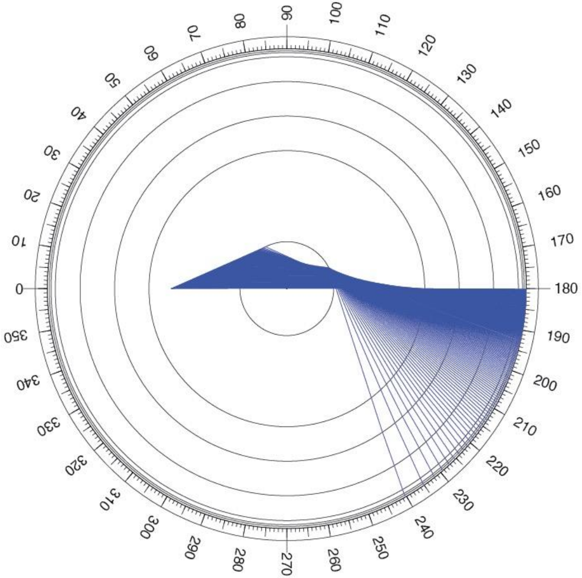


Core phase detection

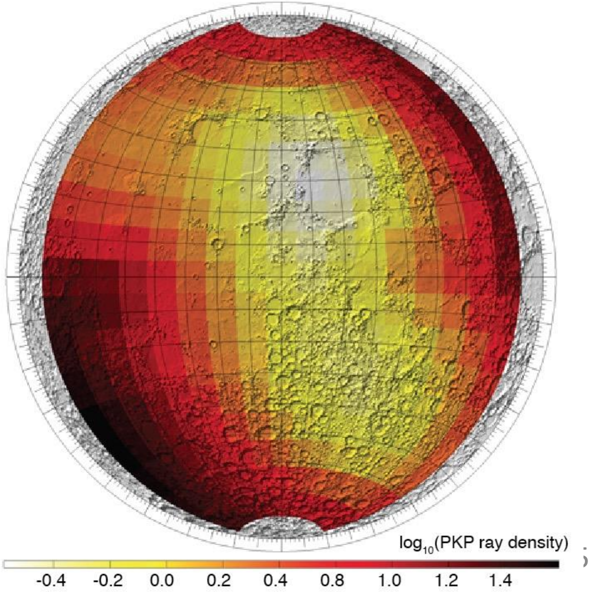
Method to map likelihood of detecting various seismic phase arrivals based on known distribution of events (adapted from Moon study)



known distribution of events



events produce core-interacting rays



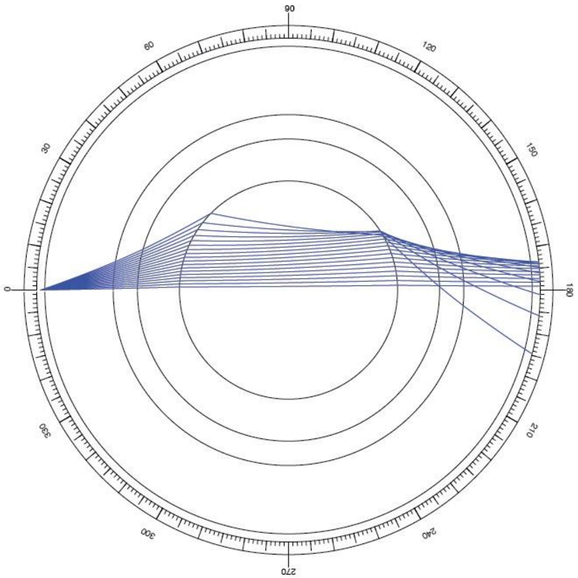
density of rays can be mapped

Ray density

ray density (η) as a function of epicentral distance (Δ):

$$\eta(\Delta) = \frac{\text{\# of rays in small interval } d\Delta}{\text{total \# of rays over all } \Delta} = \frac{\int_{\Delta - d\Delta}^{\Delta + d\Delta} \eta(\Delta') \, d\Delta'}{\int_0^{\infty} \eta(\Delta') \, d\Delta'}$$

example:
core-transmitted
phase PKP



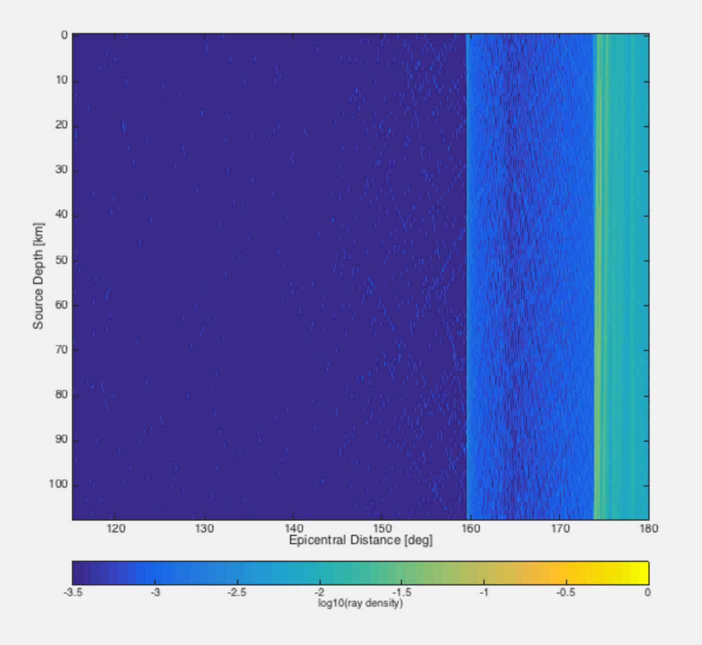
Mars model,
Sohl & Spohn 1997A

1) Generate ray density lookup table

1) $\eta(\Delta, r_{core})$

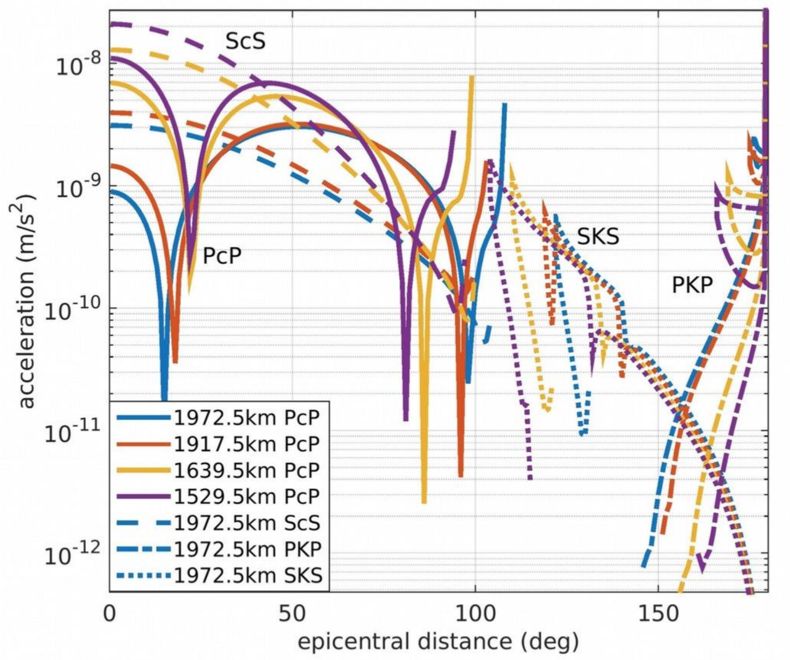
5 discrete core radii (r_{core})

distance (Δ) gridded to 0.1°

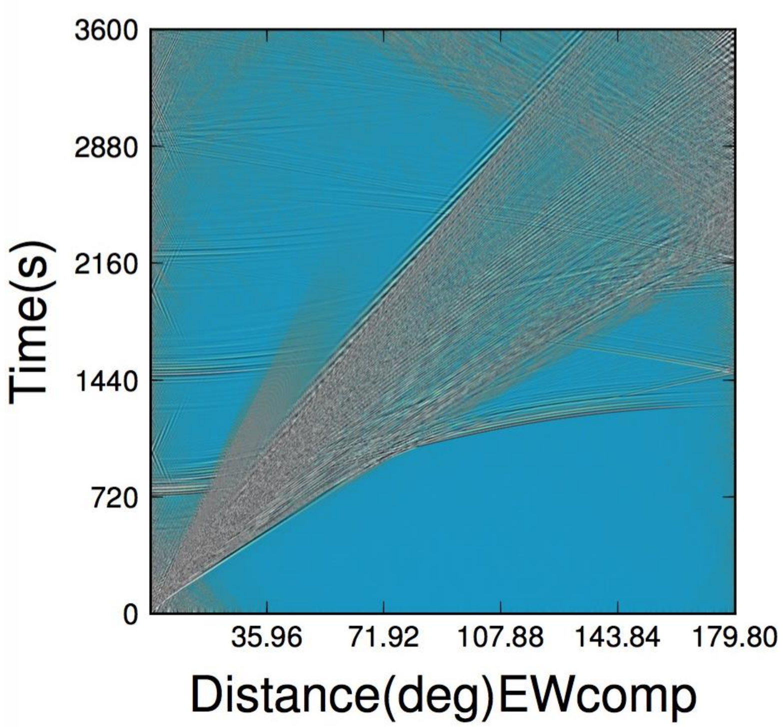


2) Generate amplitude lookup table

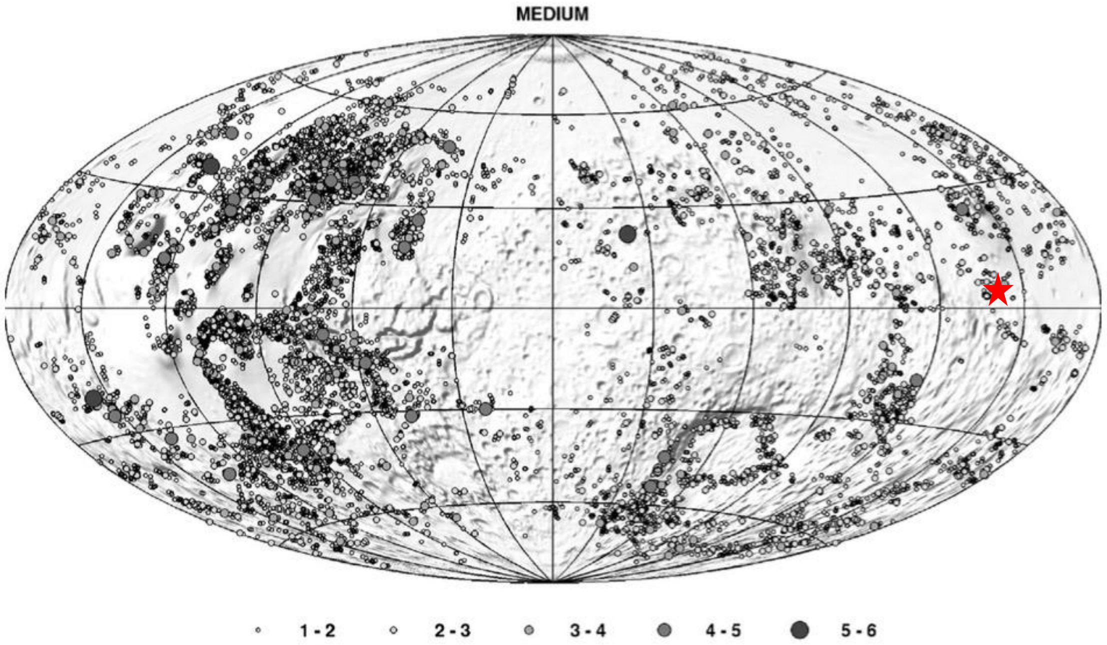
2) $\mathrm{A}(\Delta, r_{core})$ – scale factor for ray density



(compare estimates from TauP and synthetics)



2) Distribute events



Over nominal mission lifetime, create simulated event catalog drawn from surface fault distribution (Knapmeyer, 2006). Event depth is a uniformly distributed random variable based on estimated seismogenic depth (max 107km for MEDIUM seismicity model)

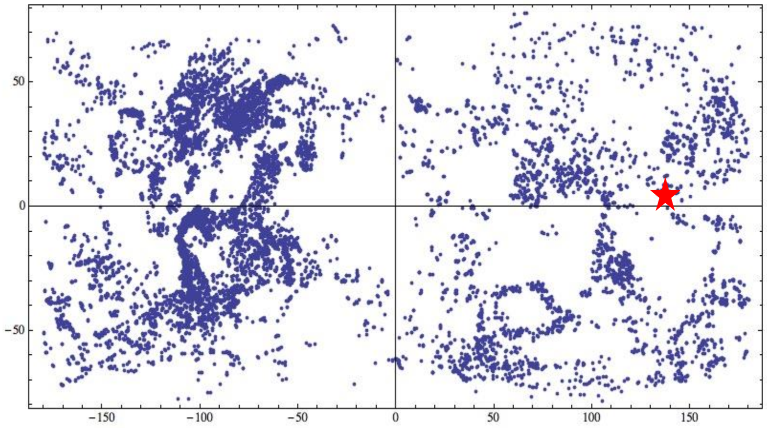
Results

3) for the i^{th} location, calculate Δ_i using (lat_i, lon_i) @ receiver location

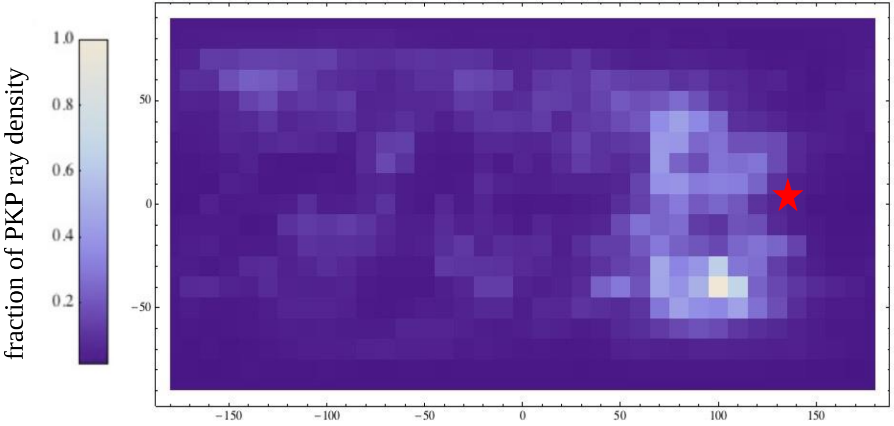
4) use the look-up table to get $A\eta(\Delta_i, z_i)$

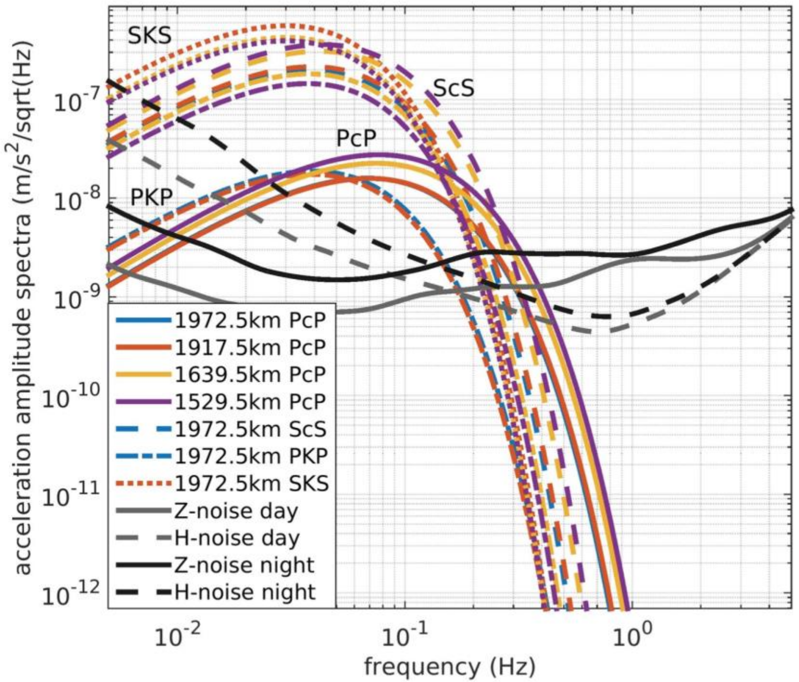
5) repeat for N events, sum over $A\eta(\Delta_i, z_i)$ and normalize by N

6) perform analysis over entire planet (potential receiver locations on a grid)



Results for 11,129 marsquakes (Knapmeyer "medium" seismicity model, intermediate number and energy of events)

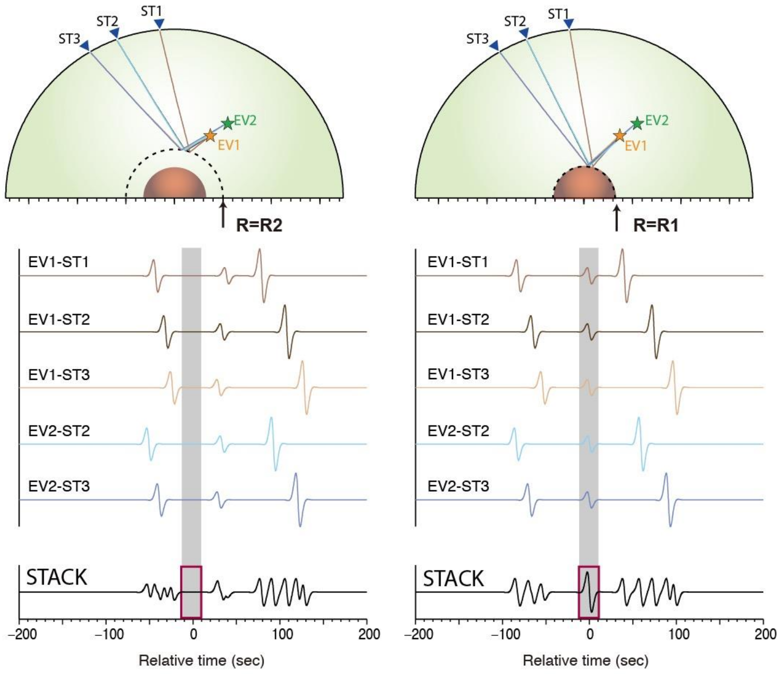




For events with M_W above 4.5, ScS and SKS signals are expected to lie above the lander noise, but PcP and PKP signals may barely be visible.

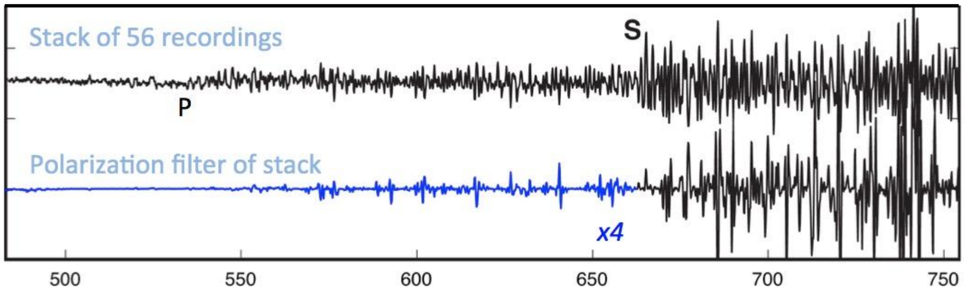
The resolution of these phases can be improved by applying stacking techniques to account for expected background noise, scattering, and interfering seismic phases. These techniques were successfully applied to Apollo seismograms to infer the radial structure of the lunar core.

Detection



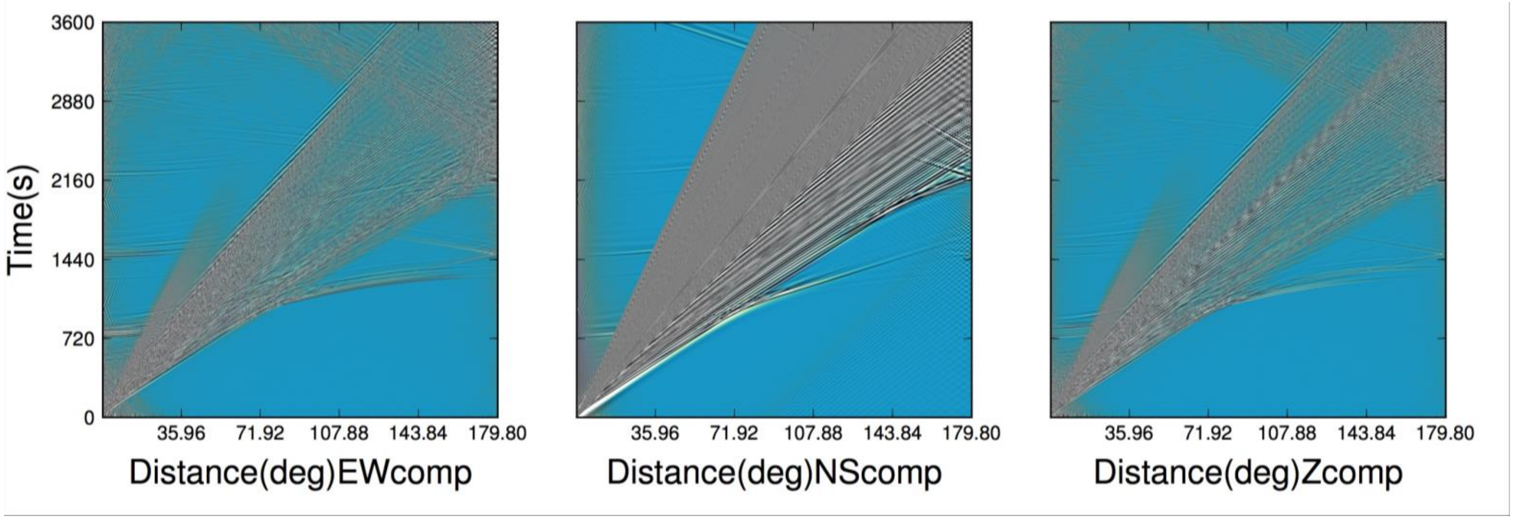
Prior to the summation of the traces of individual events, signals are aligned to a reference phase, e.g. the PcP onset assuming various core radii. A maximum in signal coherency corresponds to the best fitting core radius.

In the case of lunar seismograms, the coherency of the stacked signals was further improved by applying polarization filters. Such filtering may also be useful on Mars depending on the scattering environment of the shallow regolith.



Scattering in the crust

- Full wavefield simulations using Rivoldini models, varying CMB depth
- Observe a strong coda developing from the crust
- Apparent surface wave energy near the end of the seismograms also potentially due to crustal structure



CMB depth 1760km (radius 1629km)